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METAMORPHISM BY COMBUSTION OF THE HYDRO-CARBONS IN THE OIL-BEARING SHALE OF CALIFORNIA¹

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CONTENTS

Introduction.
Instances in Which the Shale Is at Present Burning.
Typical Occurrences of Burnt Shale.
Depth to Which Alteration Has Extended.
Lithologic Character.
Cause of the Alteration.
Range in Time of the Phenomenon.

INTRODUCTION

A unique variety of metamorphism has been at work locally in many regions of bituminous rocks in California, where a process of combustion of the hydrocarbon contents has altered the naturally white, soft shale to a rock of brilliant rose or brick-red color, and rendered it in cases hard and vesicular like scoriaceous lava. The resemblance of the products to those of volcanoes and the existence of centers like solfataras where the process of burning has been going on during the last half-century, has given rise to the statement that there were living volcanic vents in Santa Barbara County. Though the combustion is usually local in its effects, the number and wide distribution of the occurrences of burnt shale lend importance to the phenomenon. The presence of burnt shale at depths varying from 90 to 1,040 feet below the surface, as discovered in the drilling of oil wells, proves that the burning has taken place deep down within the oil-bearing formation, as well as at the surface where it has been more commonly found. And further, the discovery of fragments of it at one place at a depth of at least 10 feet below the surface in bedded deposits of Pleistocene age proves that such action has gone on not alone in recent times. The present article deals with some

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typical occurrences of shale altered in this way in the region of the oil fields of Santa Barbara County.

The Monterey shale, of middle Miocene age, is the oil-bearing formation, and the process of burning has had its chief effect upon portions of this formation. It is composed almost exclusively of soft and hard, thin-bedded, siliceous shales, which are largely of diatomaceous origin (see Fig. 1).

INSTANCES IN WHICH THE SHALE IS AT PRESENT BURNING

A number of instances have been observed in which combustion is at present or has been in recent years in progress within the Monterey shale. One example is afforded on the north side of Graciosa Ridge south of the Santa Maria Valley near the Rice Ranch oil well No. 1. When this locality was visited by the writers early in the autumn of 1906 a fire was burning underground in the shale, causing a smoke of disagreeable odor to issue from the surface and making the ground hot over an area of many square yards. Oil was oozing up at various points near by, and the ground was heated in the neighborhood of all of these seepages. The holes from which vapor issued were coated with delicate crystals of sulphur. At the point where the burning was actually going on and all about in the vicinity, for a distance of several hundred feet in some directions, the shale was altered to a bright red color, or baked almost to the hardness of compact igneous rocks, or rendered vesicular like lava.

There can be no doubt that this fire was supported by the bituminous material in the shale, and its starting was probably due to brush fires. The brush round about had been burnt, but the fire had swept over it a good many months before, as shown by the new growth on the bushes. It was said that there was a brush fire about January 1, 1906, which started the fire in the shale, and that futile attempts had been made ever since that time to put out the underground fire by dumping dirt upon it in the attempt to smother it. It seems likely, however, that this same fire has been in progress for several years. This likelihood is borne out by other accounts. It is stated that sometimes during the course of brush fires on the hills sudden darts of flame may be seen at night from a considerable distance—the result of the setting on fire of gas escaping from the rocks.

Similar phenomena were mentioned¹ by Thomas Antisell half a century ago as existing in the region near the coast east of Santa Barbara, but they were regarded by him as being of a volcanic nature. Of the foothills of the Santa Ynez Mountains a few miles east of Santa Barbara, he says:

In this part of the chain the volcanic forces can not be said to be quiescent as yet. On Dr. Robbin's ranch . . . occasionally fire, smoke, and sulphurous vapor has been emitted, from fissures in the rock, in large quantities within a few years past. A similar volcanic vent exists at Rincon.

The fire at Rincon Point referred to above, and which went popularly by the name of the "Rincon Volcano" was still active in 1890, when the vicinity was visited by Professor H. C. Ford.² In the course of his description he says,

I found hot gases bursting from numerous apertures in the shales, accompanied in some cases by melted bitumen that hardened in concretionary masses upon cooling. . . . Crystals of sulphur had also formed upon all objects near the issue, and naphtha appeared to be present. A few years ago a tunnel was run into the cliff at its base to a depth of 200 feet in search of oil. At this depth the workmen were obliged to cease operations in their endeavor to penetrate farther on account of the great heat. Upon entering this tunnel I found the temperature still high but noticed only weak sulphurous gases. Near the entrance for 50 or 60 feet the roof and sides were thickly covered with attenuated colorless crystals of epsomite hanging in tufts and masses. . . . When the excavations of the Southern Pacific Railway were made at a point a mile farther west from the locality just described, a similar issue was discovered, and upon touching a match to the gas, combustion ensued and continued, notwithstanding vigorous efforts were made to extinguish it. . . . During the summer of 1888, Mr. Richardson, who resides a short distance below the Rincon "fire wells," was startled by loud reports in their direction and upon visiting the locality observed flames issuing to the height of several feet from the apertures. Parties from Santa Barbara visited the spot upon hearing of this outburst and confirmed Mr. Richardson's observations.

The same writer mentions a similar "solfatara" on the San Marcos Ranch in the Santa Ynez Valley, and says, "Distributed over the surface were eight or ten apertures from which rose visible sulphurous fumes to the height of from two to three feet." He found the tem-

¹ *Explorations and Surveys for the Pacific Railroad*, Vol. VII, p. 71, Washington, 1857.

² *Bull. Santa Barbara Soc. Nat. Hist.*, Vol. I, No. 2, October, 1890.

perature of the gases upon their issue "to be so high that the hand could not for a moment bear the heat." It is not known to the writers whether these fires are still burning.

TYPICAL OCCURRENCES OF BURNT SHALE

The Santa Maria oil district in northern Santa Barbara County is rich in outcrops of rose-colored shale and other products of the burning process, these occurring in eight or ten separate localities. The best examples are along the ridge bordering the Santa Maria Valley some eight miles southwest of Santa Maria; on the north and south sides of Graciosa Ridge, a similar distance south of that town; and on Redrock Mountain, four miles southeast of Los Alamos. In each of these regions every stage of alteration is exhibited from the slightly discolored shale to hard slag-like rocks of varying shades of red and black (see Fig. 2). The area of altered shale in the different localities varies from a small one of some hundred square feet to one of half a square mile or more, as at Redrock Mountain. They are in every case surrounded by unaltered, usually soft, white, diatomaceous shale, which in the majority of cases shows the planes of stratification (see Fig. 1). No case was observed in which a sign of stratification was left in the baked shale. In every case the shale in the neighborhood is bituminous and asphalt deposits are usually adjacent.

The largest area of altered shale in this region is on the summit and surrounding ridges of Redrock Mountain south of Los Alamos. This is the highest of the hills in the basin region between the San Rafael and Santa Ynez Mountains, being 1,968 feet above the sea, while the usual height of the summits round about is from 1,000 to 1,500 feet. It seems to owe its prominence, at least in part, to the metamorphosed shale forming its summit. In the case likewise of the 800-foot hill on the southeast side of the Southern Pacific Railroad coast line at Schumann Pass, the capping of volcanic-looking rock of this same character seems to have caused the topographic relief. The metamorphism in these cases probably took place a long time ago. At Redrock Mountain, in places in contact with the altered shale, are great deposits of asphalt and a large area of shale impregnated with bitumen.

DEPTH TO WHICH ALTERATION HAS EXTENDED

The depth to which alteration has extended below the surface in these cases is difficult to determine. A cliff of burnt shale 50 to 100 feet high is exposed $4\frac{1}{2}$ miles due south of Guadalupe, and the difference of elevation of points in the Redrock Mountain neighborhood where the altered rock outcrops amounts to several hundred feet.



FIG. 1.—Hand specimen of typical diatomaceous shale from the Santa Maria oil district, Santa Barbara County, California (slightly reduced).

That such metamorphism of the shale has not been solely a surface phenomenon is shown by the fact that burnt shale has been found on drilling at considerable depths. Mr. Orcutt, of the Union Oil Company, exhibited samples of red shale, coming from depths of 950 to 1,040 feet below the surface in Hill well No. 1 in the Lompoc Field, which are identical in appearance and texture with the burnt shale elsewhere. Traces of petroleum were associated with the upper stratum of burnt shale in this instance. There are numerous wells in the Santa Maria field in which red shale, doubtless burnt, was met with at depths varying between 90 feet and 330 feet below the surface. The hardening consequent upon the burning has sometimes rendered the rock difficult to drill through.

LITHOLOGIC CHARACTER

The burnt shale exhibits all stages of change from slight induration and discolorization due probably to oxidation of iron, to extreme hardening, and partial fusion. When slightly altered the normal white shale assumes a light pink color. From this stage it passes through various shades of rose and brick red and deepens in color to

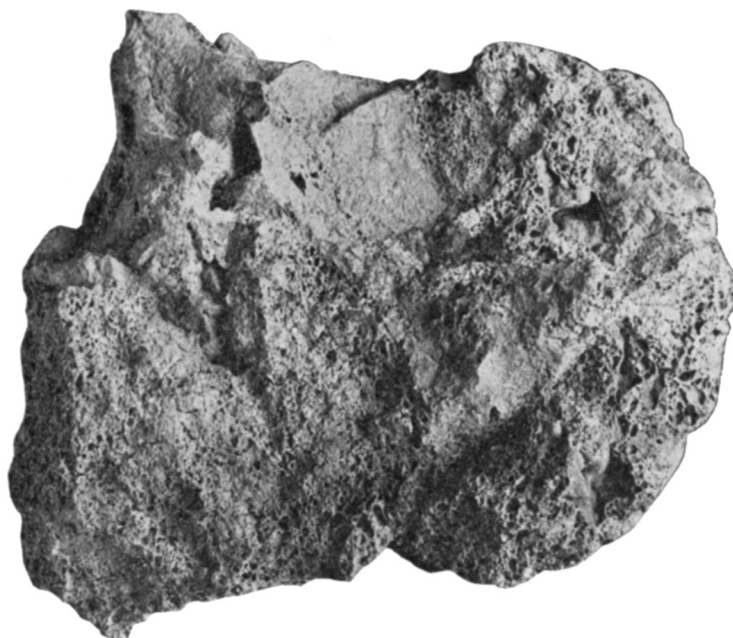


FIG. 2.—Hand specimen of a similar shale after metamorphism by burning (slightly reduced).

a reddish, bluish, or greenish black or true black. In the advanced stages of change it becomes a rough, brittle, reddish, porous slag just like vesicular lava, like that shown in Fig. 2, or a very hard, compact, dark and dull-colored rock looking somewhat like a compact igneous rock. It is not crystalline, but the texture is variable so as to give a patchy appearance to surfaces. In one place it will be compact and black, nearby full of irregular cavities surrounded by patches of different colors, or again vesicular and reddish. Whereas the weight

of the original shale is slight, the lighter varieties having a specific gravity less than that of water, the excessively burnt shale is very heavy. The material has evidently contracted to much less than its original volume, the angular cavities and irregular vesicles being one consequence of this contraction.

Under the microscope the more advanced stages appear as having an exceedingly fine-grained, amorphous, porous ground-mass discolored with a reddish brown or gray stain. Black filaments and dots appearing like carbonaceous material are common. Exceedingly minute rounded and irregular grains scattered through the whole, but forming no appreciable proportion of it, are the only portions visible under crossed nicols. They extinguish four times in a revolution of the field, and are probably clastic quartz grains. These are characteristic of the unaltered shale as well.

Mr. George H. Eldridge remarks¹ on an occurrence of burnt shale in the Santa Maria field near the old Blake asphalt mine south of Graciosa Ridge. He says, "The shale now appears red, ash-like to hard and clinker-like, glazed or silicified; bodies of bitumen contained within this have the appearance of a coke, as though derived from the solid fixed carbon of the petroleum."

The likeness of varieties of the burnt shale to volcanic rocks is indicated by the fact that Thomas Antisell in his account of the geology of the Coast Ranges in the Pacific Railroad Report,² describes "scoriaceous" and "amygdaloidal lava," "whitish-gray, hard trachytic rock," "volcanic," and "igneous rocks" in the region of the Santa Ynez River, evidently having reference to the burnt shale. He considered it to be in eruptive masses, forming the oldest and axial rocks of the hill ranges, whereas it is part of the Monterey shale formation which overlies the basement formations. He regarded the associated diatomaceous shales in some places, although not in others, as "magnesian" and "tremalite" rocks of igneous origin. He refers to the places where the shale is burning as examples of present volcanic activity.

¹ "The Asphalt and Bituminous Rock Deposits of the United States," *Twenty-second Annual Report, U. S. Geological Survey*, 1901, Pt. I, p. 428.

² *Explorations and Surveys for the Pacific Railroad*, Vol. VII, pp. 65-72. Washington, 1857.

CAUSE OF THE ALTERATION

There can be little doubt that the burnt shale is in all cases the result of heat produced by combustion of the hydro-carbon contents of the shale. The phenomenon is confined to the Monterey shale, which is the source of a large part of the California petroleum, and to those regions in which this formation is extremely bituminous. The shale in such places is frequently impregnated with petroleum and the cracks partially filled with it. The altered shale areas are almost invariably situated in the vicinity of oil seepages, which usually connote a fractured condition of the rocks such as would allow fire to spread and be supported. The observance of fires actually in progress in the shale and the changes that have taken place in the rocks round about—changes in every way similar to those in localities of the metamorphosed shale where no fire exists at present—gives the best of clues to the manner in which the shale has been baked in other cases. It is difficult to conceive of a source of heat sufficient to cause local baking of the shale in otherwise unaltered strata at a depth of 1,000 feet below the surface in such a case as has been mentioned. Probably there, as on the surface, it was due to ignition of bituminous material. It is probable that fire started in the petroliferous shale at the surface and threaded its way downward along cracks partially filled with bitumen or gaseous hydrocarbons. The failure to smother the fire in the shale on Graciosa Ridge, as previously mentioned, indicates that such fires are able to survive with a limited air supply. On the other hand if the above theory is correct it indicates that a considerable amount of oxygen may be present in the rocks at such a depth.

The cause of ignition may be kindled fires, lightning, or the spontaneous combustion of the hydrocarbons or surface vegetation. Many of the recent cases of burning are directly traceable to the first cause, but for those which may have taken place before the advent of man, either the second or third cause will have to be invoked.

Burnt shale was noticed by J. D. Whitney in the vicinity of Santa Barbara, and its origin rightly interpreted. He says of it:

About five miles southeast of Carpinteria, the rock presents exactly the appearance of having had the bituminous matter burned out of it; it assumes various

colors, such as bright red, rose, brown, yellow, and cream color and it appears to have been partially fused in some places. ¹

And again he remarks, referring to the same region.

In some localities the rock has evidently been on fire, and the bituminous matter having been burned out—the operation continuing for several years, as it is said—the slates are left of various shades of red, produced by the oxidation of the iron.²

Burnt-shale areas occur in many places besides in Santa Barbara County. Mr. G. H. Eldridge³ makes the following comment on its occurrence and origin in Ventura County where especially good examples are to be found south of the valley of the Santa Clara River on Oak Ridge and the crest of South Mountain.

The siliceous shale and “chalk rock” forming the crest of the mountains south of the Santa Clara have at many points been burned to a bright red color. The fuel which supported such fires was perhaps the originally contained petroleum.

Opposed to this view, however, is the very considerable depth to which the shale has been altered to a brilliant red lava-like rock; hence it may be inferred that spontaneous combustion alone has brought about the modification.

RANGE IN TIME OF THE PHENOMENON

As already mentioned, the marked influence of the hardened shale on the topography in certain instances points to its origin in those cases a long time since. The age of some of the burnt shale areas is further shown by the presence of numerous fragments of it at a depth of at least ten feet below the surface in horizontal beds of Pleistocene age. These beds are of sand, clay, and rough gravel, and form the low hills between Guadalupe Lake and the high hills to the west. The fragments of shale are little worn and evidently of local derivation; having very possibly come from the cliffs before mentioned south of Guadalupe. The fact that the Monterey shale underwent this kind of baking in Pleistocene times indicates further that the accumulation of the oil and its dissemination in the surface rocks took place, or was taking place, before the latest orogenic movements in this coastal region.

¹ “Geol. Survey of California,” 1865, *Geology*, Vol. I, p. 126.

² *Ibid.*, p. 131.

³ G. H. Eldridge and Ralph Arnold, “The Santa Clara Valley, Puente Hills and Los Angeles Oil Districts,” *Bull. 309, U. S. Geol. Survey*, p. 22, 1907.